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Draw a cross through the box (☒) if you have NOT written in this booklet

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Physics 2023

91526 Demonstrate understanding of electrical systems

Credits: Six

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of electrical systems.	Demonstrate in-depth understanding of electrical systems.	Demonstrate comprehensive understanding of electrical systems.

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

Make sure that you have Resource Booklet L3–PHYSR.

In your answers use clear numerical working, words, and/or diagrams as required.

Numerical answers should be given with an appropriate SI unit.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–12 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area (DO NOT WRITE IN THIS AREA). This area will be cut off when the booklet is marked.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Achievement **10**

QUESTION ONE: CAPACITORS

Kate is learning about capacitors. She investigates a capacitor found in a camera. The capacitor is labelled 185 nF (1.85×10^{-7} F).

(a) The camera also contains a 1.50 V ("AA") battery.

Show that the energy stored by the capacitor, when it is fully charged by connecting it to the battery, is 2.08×10^{-7} J.

$Q = CV$

$Q = 1.85\times10^{-7} \times \cancel{2.08\times10^{-7}}\ 1.50$

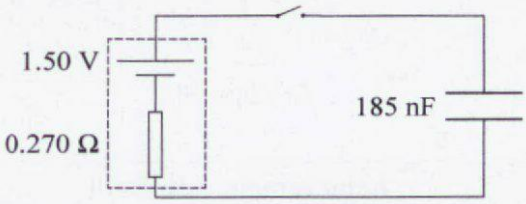
$Q = 2.775\times10^{-7}$ C

$E = \frac{1}{2}QV$

$E = \frac{1}{2} 2.775\times10^{-7} \times 1.5$

$E = 2.08\times10^{-7}$ J

(b) The diagram below shows the circuit used to charge the capacitor. The battery has an internal resistance of 0.270 Ω. Assume the rest of the circuit has no resistance.



Sketch a curve by plotting at least four points on the grid opposite to show how the charge on the capacitor plates varies with time, once the switch is closed.

Your answer should indicate:

- the time constant for charging the capacitor
- the maximum charge that will be stored on the capacitor plates.

Show all calculations clearly.

$Q = CV$

$Q = 1.85\times10^{-7} \times 1.50$

$Q = 2.775\times10^{-7}$ C

or $Q = 27.8\times10^{-8}$ C

$\tau = RC$

$\tau = 0.270 \times 1.85\times10^{-7}$

$\tau = 4.995\times10^{-8}$ s

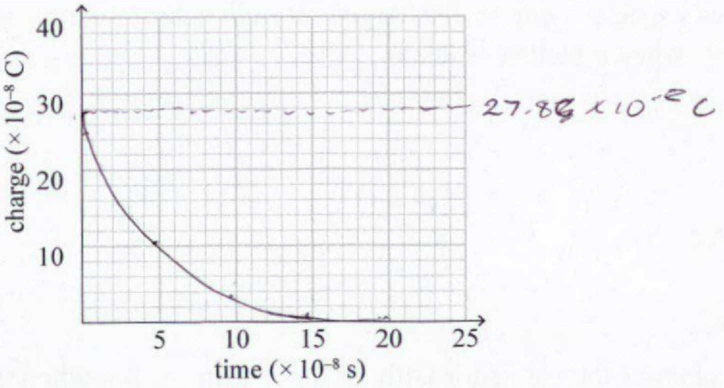
$\tau = 4.96\times10^{-8}$ s

For Q_1: $2.775\times10^{-7}\times0.37 = 1.02675\times10^{-7}$ C

$Q_2 = 1.02675\times10^{-7}\times0.37 = 3.798975\times10^{-8}$ C

$Q_3 = Q_2\times0.37 = 1.4056207\text{5}\times10^{-7}$ C

$Q_4 = Q_3\times0.37 = 5.200796775\times10^{-9}$ C



If you need to redraw your response, use the grid on page 10.

(c) Although the capacitor plates are rolled up, they act like two metal rectangles measuring 3.2×10^{-2} m × 1.83 m, with dielectric material in between.

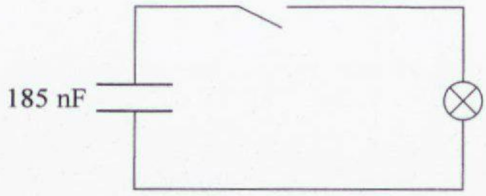
If the dielectric material in the capacitor has a relative permittivity of 2.10, calculate the distance between the metal rectangles.

$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ $\quad d = \frac{\varepsilon_0 \varepsilon_r A}{C}$ $\quad A = 0.05856 \text{ m}^2$

$d = \frac{8.85 \times 10^{-12} \times 2.10 \times 0.05856}{1.85 \times 10^{-7}}$

$d = 5.88 \times 10^{-6}$ m

(d) The charged capacitor can be discharged through a lamp by pressing a switch. In the camera, the lamp flashes when a picture is taken.



Kate fully charges the capacitor with the 1.5 V battery, but when the bulb is connected, it barely glows. Inside the camera she finds wiring that allows the capacitor to be charged to 200 V.

Explain how this arrangement allows for a much more powerful flash.

In your answer you should show:

- how the energy stored in a fully-charged capacitor at 200 V compares with 1.5 V
- how the higher voltage increases the initial current from the capacitor when it is connected to the bulb
- how the brightness of the flash will be affected by the higher voltage.

A capacitor stores energy by storing opposite charges on its two plates. A capacitor ~~which~~ at 200V stores a far larger amount of opposite charges on its two plates when compared to a 1.5V capacitor, hence, the 200V capacitor can store more energy.

Because I can be modelled using $I = \frac{V}{R}$, and because R remains the same in this circuit (no new resistance being added) a larger V will result in a larger I when the switch is closed as ~~a~~ the same value of R must divide a larger value V (200V vs 1.5V), resulting in a larger ~~flow of~~ current.

Because the brightness of the flash is dependent upon power (P) and P = IV, both a larger value of I and V will result in a larger value for P, thus increasing the brightness of the flash.

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The assessment continues on the following page.

QUESTION TWO : TRANSFORMERS AND INDUCTORS

Kate's school has a demonstration transformer, pictured alongside. She connects the 12 000-turn primary coil (red in the picture) to the mains supply (240 V rms).

Source: www.findel-international.com/product/science/physics/electricity-and-electromagnetism/dissectible-transformer/e8h26564

(a) She connects an AC voltmeter to the blue coil.

Calculate the rms voltage she would measure from the 600-turn secondary coil.

$\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $\frac{12000}{600} = 20$

$\frac{V_p}{V_s} = 20$ $V_s = \frac{240}{20}$ $V_s = 12\,V$ rms.

(b) The two coils are held by a ring of laminated soft iron, which runs through the core of each coil.

Explain why:

- an AC voltage in the red coil produces an AC voltage in the blue (secondary) coil
- the coils are wrapped around an iron ring.

An AC voltage in the red coil produces an AC voltage in the blue coil as the red coils' ~~flux~~ magnetic flux is carried over into the blue coil, which, because the magnetic flux is alternating, an alternating current is produced and thus, an AC voltage is produced in the secondary coil.

By wrapping the coils around an iron ring, the magnetic field (B) is made greater, which then also makes the alternating magnetic flux (ϕ) greater strength as per $\phi = BA$, where B has increased and A has remained the same.

(c) Kate connects the 12 000-turn primary coil in a circuit with a 12 V battery (DC) and a 12 V car headlamp bulb. (The cores of the coils are still linked with iron.)

This means that $\Delta\Phi$ is large, making $\mathcal{E}$ larger as $\mathcal{E} = -\frac{\Delta\Phi}{\Delta t}$

Explain why the headlamp bulb only comes on after a slight delay.

The primary coil acts an inductor which creates a back EMF to oppose the change in current. It is because of this that the headlamp bulb has a delay, as not all the current begins flowing through the bulb when the circuit is connected. Instead, there is a short period of time where the flow of current must gradually increase to ~~a~~ high enough level where it overcomes the back EMF and is able to supply the bulb ~~to~~ so that it glows.

50,000 W

(d) The power station that supplies Kate's area generates 50 kW of power. The transmission line near Kate's house carries 50 kW of power to an industrial user. The voltage across the transmission line is 220 kV. The resistance of the transmission line is 4.00 Ω for every kilometre.

220,000 V

Calculate the power lost as heat energy across a distance of 300 km.

Comment whether this amount calculated is significant compared to a situation where the voltage is not stepped up to 220 kV, but is transmitted at 25 kV.

$4.00\,\Omega \times 300 = 1200\,\Omega$

P

V

R

$P = IV$ $\quad$ $P = 733.3333333 \times 220,000$

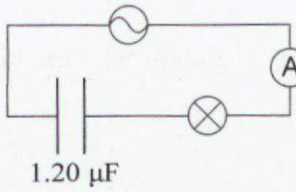
$I = \frac{V}{R}$ $\quad$ $P = 161,333,333\,W$? doesn't seem right haha

$I = 733.3333333\,A$

If the voltage were transmitted at 25 kV, that is, 25,000 V, then the overall loss of power to heat energy would be ~~less~~ lower, as a decrease in V would result in a smaller I as $I = \frac{V}{R}$. $P = IV$, and so both a smaller I and a smaller V would result in a lower loss of power.

QUESTION THREE: ALTERNATING CURRENT (AC)

Kate builds a circuit with a signal generator set at 200 Hz, an AC ammeter, a lamp (15.0 Ω), and a capacitor (1.20 μF) in series.



(a) Show that the capacitive reactance (X_c) is 663 Ω, and hence determine the impedance of the circuit.

$C = 1.20 \times 10^{-6}$ c $\qquad \omega = 2\pi f = 2\pi \times 200$

$X_C = \frac{1}{\omega C} = \frac{1}{400\pi \times 1.20 \times 10^{-6}} \qquad \omega = 400\pi \text{ rads}^{-1}$

$X_C = 663\,\Omega.$

$Z = 663\,\Omega + 15\,\Omega = 678\,\Omega.$

(b) Kate increases the frequency of the signal generator from 200 Hz to 20 kHz, and then to 200 kHz.

Give an in-depth explanation of what Kate will observe in the circuit at each frequency compared to her observation in part (a).

In your answer consider the effect of changing the frequency on:

- the impedance of the circuit ~~↑~~ ↓
- the rms current ↑
- the brightness of the lamp. ↑

When Kate increases the f to 20kHz (20,000 Hz), she will find that the impedance of the circuit will decrease, as $Z = R + X_L + X_C$ and $X_C = \frac{1}{\omega C}$ and $\omega = 2\pi f$. This would then mean that rms current would increase as ~~it is then~~ current is now resisted/opposed/impeded by a lower total ~~x~~ impedance. This would then increase the power ~~bein~~ being sent to the bulb, as $P = IV_{rms}$ and I_{rms} would be larger. The effects on all three of these variables would be even more pronounced at 200,000 Hz, as impedance would be even lower, making I_{rms} even larger and the lamp even brighter!

Kate adds a 0.200 H inductor in series with the capacitor.

(c) While the signal generator is set at 2000 Hz, the lamp is off, but as she slowly decreases its frequency, the lamp suddenly glows brightly, but then goes off at lower frequencies.

Calculate the frequency at which the bulb glows brightest.

~~X_L~~ $X_c = X_L$ $L = 0.200H$

$X_L = \omega L$ $C = 1.20 \times 10^{-6}$ C

$X_L = 0.200 \times 2\pi \times f$ $f = ?$

$X_L = 0.400\pi \times f$

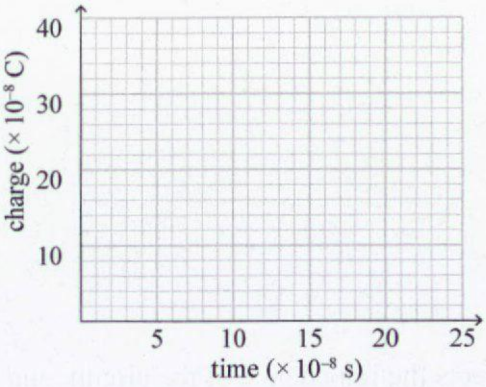
(d) Explain how the inductor affects the impedance of the circuit, and why there is one frequency at which the impedance equals the resistance of the circuit (15.0 Ω), causing the lamp to glow brightly.

The introduction of the ~~Resonance~~ inductor will increase the impedance of the circuit as $Z = R + X_c + X_L$, and where X_L was previously non-existant due to the lack of an inductor, a value for X_L now exists ~~thanks~~ thanks to the introduction of an inductor.

When $X_L = X_c$, resonance occurs, which is when ~~the~~ oscillations or stored energy are transferred from the inductor into the capacitor, resulting in the highest possible amplitude of power possible. There is one particular value of f which allows for resonance to occur ~~at~~, where $\omega L = \frac{1}{\omega C}$ and $\omega = 2\pi f$, which is why the lamp glows brightest at one particular frequency.

SPARE DIAGRAM

If you need to redraw your response to Question One (b), use the grid below. Make sure it is clear which answer you want marked.



Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

Extra space if required.
Write the question number(s) if applicable.

QUESTION NUMBER

91526

Standard	91526			Total score	10
Q	**Grade score**	**Marker commentary**			
1	A4	b) The candidate has correctly calculated the time constant. d) There is no qualitative comparison of the energy stored at 200V or that the higher voltage means the current increases 133x or that the current is larger because more charges are released in the same time.			
2	A3	b) The candidate states the use of the iron ring but incorrectly explains that an alternating current is produced in the transformer. d) Both the calculation and statement about the power lost are incorrect.			
3	A3	a) The candidate has shown that $X_C = 623\Omega$ but has used an incorrect method to calculate the impedance. b) The justification for the decrease in the reactance is correct but the formula given to justify the decrease in the impedance is wrong. d) There is no indication that X_L and X_C are 180° out of phase and cancel out at resonance.			